

The multiplicity of planet host stars

— New low-mass companions to planet host stars

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ABSTRACT

We present new results from our ongoing multiplicity study of exoplanet host stars, carried out with the infrared camera SofI at ESO-NTT. We have identified new low mass companions to the planet host stars HD 101930 and HD 65216. HD 101930 AB is a wide binary systems composed of the planet host star HD 101930 A and its companion HD 101930 B which is a M0 to M1 dwarf with a mass of about $0.7 M_{\odot}$ separated from the primary by ~ 73 arcsec (2200 AU projected separation). HD 65216 forms a hierarchical triple system, with a projected separation of 253 AU (angular separation of about 7 arcsec) between the planet host star HD 65216 A and its close binary companion HD 65216 BC, whose two components are separated by only ~ 0.17 arcsec (6 AU of projected separation). Two VLT-NACO images separated by 3 years confirm that this system is co-moving to the planet host star. The infrared photometry of HD 65216 B and C is consistent with a M7 to M8 ($0.089 M_{\odot}$), and a L2 to L3 dwarf ($0.078 M_{\odot}$), respectively, both close to the sub-stellar limit. An infrared spectrum with VLT-ISAAC of the pair HD 65216 BC, even though not resolved spatially, confirms this late spectral type. Furthermore, we present H- and K-band ISAAC infrared spectra of HD 16141 B, the recently detected co-moving companion of the planet host star HD 16141 A. The infrared spectroscopy as well as the apparent infrared photometry of HD 16141 B are both fully consistent with a M2 to M3 dwarf located at the distance of the planet host star.

Key words: stars: individual: HD16141, HD65216, HD101930, stars: low-mass binaries: visual, planetary systems

1 INTRODUCTION

Since the mid nineties of the last century high precision radial-velocity studies revealed more than 200 exoplanet candidates around mostly solar-like stars. These planet host stars are located in the solar neighborhood and are mostly isolated single stars. However, already among the first reported planet detections, three planets were found to orbit the brighter component of binary systems, namely 55 Cnc AB, ν And AB and τ Boo AB (Butler et al. 1997).

Since that time more and more planet host multiple star systems were identified, most of them being found in multiplicity studies of the planet host stars. These studies

are carried out with seeing limited near infrared imaging (see e.g. Mugrauer et al. 2004a&b, 2005, 2006a) as well as high contrast diffraction limited AO observations (Patience et al. 2002, Luhman & Jayawardhana 2002, Chauvin et al. 2006, and most recently Neuhauser et al. 2007). In addition, data from visible and infrared all sky surveys like POSS or 2MASS are used to identify new companions of planet host stars (see e.g. Bakos et al. 2006 or Raghavan et al. 2006). Because of all these efforts, more than 30 planet host multiple star systems are known today, suggesting that the multiplicity of planet host stars is at least 20 %.

Most of the detected stellar companions to planet host stars are low-mass main sequence stars. The projected separations of these companions to the planet host stars range from only a few tens of AU up to more than 5000 AU. In a few cases the companions themselves turned out to be close binaries, i.e. these systems are hierarchical triples (see Mugrauer et al. 2007 for a summary). Not only main-sequence

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stars but also white dwarfs were revealed as companions of exoplanet host stars, suggesting that planetary systems also exist in evolved multiple star systems. Three white dwarfs were found so far at close (G186 B, ~ 20 AU, see Mugrauer & Neuhauser 2005, Lagrange et al. 2006), intermediate (HD 27442 B at ~ 240 AU, see Chauvin et al. 2006 and Mugrauer et al. 2007) and at wide separations (HD 147513 B at ~ 5400 AU, see Mayor et al. 2004). Recently, the first directly imaged substellar companion of an exoplanet host star, the $T7.5 \pm 0.5$ brown dwarf HD 3651 B, was discovered (see Mugrauer et al. 2006b, Burgasser 2006, Liu et al. 2007, and Luhman et al. 2007).

In this letter we present new results of our multiplicity study carried out with the ESO-NTT at La Silla observatory. We have discovered new stellar companions to two planet host stars. We show the results of our near infrared imaging observations in section 2. Section 3 summarizes the infrared H- and K-band spectroscopic data obtained for the new companions presented here, and also for the close planet host star companion HD 16141 B, for which we have already presented the astrometric confirmation of companionship in Mugrauer et al. (2005). In the last section we discuss the properties of the newly found companions.

2 OBSERVATIONS

HD 65216 is a nearby G5 dwarf, located in the southern constellation Carina. Its proper motion and parallax ($\mu_\alpha \cos(\delta) = -122.12 \pm 0.98$ mas/yr, $\mu_\delta = 145.90 \pm 0.64$ mas/yr, and $\pi = 28.10 \pm 0.69$ mas) are both determined by Hipparcos (Perryman et al. 1997), yielding a distance of ~ 36 pc. According to Santos et al. (2004) HD 65216 has an effective temperature of 5666 ± 31 K and a surface gravity of $\log(g) = 4.53 \pm 0.09$ cm/s², as expected for a mid G main-sequence star. The same group also determined the mass of the star to be $0.94 M_\odot$. Saffe et al. (2005) derived an upper age limit for HD 65216 to be 10.2 Gyr, obtained from the stellar metallicity ($[Fe/H] = -0.12$). A variation of the radial velocity of HD 65216 with a period of 613 day is reported by Mayor et al. (2004), indicating that the star is orbited by a Jupiter-mass planet ($m \cdot \sin(i) = 1.21 M_{Jup}$) on an eccentric ($e = 0.41$) orbit with a semi-major axis of $a = 1.37$ AU.

HD 101930 is a nearby (31 pc) dwarf of spectral type early K, located in the southern part of the constellation Centaurus, close to the famous constellation Southern Crux. The proper motion and parallax of HD 101930 are both well known from precise Hipparcos measurements ($\mu_\alpha \cos(\delta) = 15.00 \pm 1.01$ mas/yr, $\mu_\delta = 347.49 \pm 0.80$ mas/yr, and $\pi = 32.79 \pm 0.96$ mas). Lovis et al. (2005) determined its effective temperature to 5079 ± 62 K and surface gravity to $\log(g) = 4.24 \pm 0.16$ cm/s². Both values are consistent with an early K dwarf. The authors also derived the mass of this star to be $0.74 M_\odot$. According to Saffe et al. (2005) the age of HD 101930 ranges between 3.5 and 5.4 Gyr. HD 101930 is chromospherically inactive ($\log R'_{HK} = -4.99 \pm 0.02$) but shows a periodical modulation of its radial velocity (Lovis et al. 2005). This variation of the stellar radial-velocity is induced by a Saturn-mass exoplanet ($m \cdot \sin(i) = 0.3 M_{Jup}$), which orbits the star every 70 days ($a = 0.30$ AU) on a slightly eccentric orbit ($e = 0.11$).

We observed HD 65216 and HD 101930 for our multiplicity study of planet host stars, using the infrared camera SofI at the ESO-NTT at La Silla observatory. All observations were obtained in the H-band with the SofI small-field camera (147 arcsec \times 147 arcsec field of view). By comparing two images of the planet host stars taken at different observing epochs we can find co-moving companions of these stars and distinguish them from non- or only slowly moving background sources.

The first epoch observations of HD 65216 and HD 101930 were both obtained in June 2005 with follow-up second epoch imaging one year later in June 2006. In order to limit saturation effects of the detector due to the bright planet host stars, we always used the shortest available integration time (1.2 s), and 50 of these 1.2 s integrations were averaged to one image. The standard dither (jitter) technique was applied to subtract the bright infrared sky background. In total 10 images were taken at 10 different dither positions, resulting in a total integration time of 10 min. The data reduction, i.e. background estimation and subtraction, flat-fielding of all images as well as the final shift and add procedure was done with the ESO data reduction package *ECLIPSE* (Devillard 2001).

Figure 1 shows our second epoch SofI H-band images of HD 65216 and HD 101930, in which the primaries are located in the center of each image.

All images are astrometrically calibrated with sources detected in our SofI images and listed in the 2MASS point source catalogue (Skrutskie et al. 2006). The astrometric calibration of both SofI observing runs is summarized in Tab. 2.

By comparing our first epoch H-band images with the second epoch images we determined the proper motion of all objects ($S/N > 10$) detected around the planet host stars within the SofI field of view. As illustrated in Fig. 2, most of the detected objects have a small or even negligible proper motion. However, we have identified two sources which share the proper motion of the planet host stars, indicated as boxes in Fig. 2. Thus, these sources are co-moving companions of the planet host stars and will be denoted HD 65216 B and HD 101930 B from hereon.

We measured the H-band photometry and relative astrometry of both detected co-moving companions in our SofI H-band images. The results are summarized in Tab. 2. HD 101930 B is already too bright and exceeds the linearity limit of the SofI detector, hence we cannot give an accurate H-band photometry of this object. However, this object is well detected in 2MASS and accurate photometry (photometric quality flag: AAA) of this companion is listed in the 2MASS point source catalogue ($J = 7.940 \pm 0.026$, $H = 7.291 \pm 0.049$, $K_S = 7.107 \pm 0.024$), see Skrutskie et al. (2006). We used the 2MASS astrometry and derived the separation and position angle of HD 101930 B relative to the planet host star at the epoch of the 2MASS observations (see Tab. 2).

HD 101930 B is also listed in the UCAC2 catalogue (Zacharias et al. 2004), in the USNO-B1.0 (Monet et al. 2003), as well as by Kharchenko (2001). The UCAC2 ($\mu_\alpha \cos(\delta) = 25.6 \pm 3.3$ mas/yr, $\mu_\delta = 349.2 \pm 3.0$ mas/yr) and USNO entry ($\mu_\alpha \cos(\delta) = 24$ mas/yr, $\mu_\delta = 348$ mas/yr), as well as the astrometry of HD 101930 B given by Kharchenko (2001) ($\mu_\alpha \cos(\delta) = 24.99 \pm 4.02$ mas/yr, $\mu_\delta = 351.55 \pm$

Table 1. Pixel scale and detector orientation with their uncertainties for all SofI observing runs. The detector is tilted by the given angle from north to west. Furthermore, the separations and position angles of the detected companions HD 65216 B and HD 101930 B relative to their primaries – the exoplanet host stars HD 65216 A and HD 101930 A – as well as their H-band photometry are listed, as measured in all SofI observing epochs.

Calibration & Seeing	epoch date	pixel scale [arcsec/pixel]	detector orientation [°]	average seeing [arcsec]
	SofI 06/05	0.14330±0.00020	90.040±0.048	1.2
	SofI 06/06	0.14348±0.00016	90.017±0.049	1.0
Astrometry & Photometry	epoch date	separation [arcsec]	position angle [°]	H magnitude [mag]
HD 65216 B	SofI 06/05	7.097±0.030	89.68±0.25	12.674±0.063
	SofI 06/06	7.144±0.028	89.39±0.23	12.685±0.063
HD 101930 B	2MASS 01/00	73.079±0.085	8.28±0.07	7.291±0.049
	SofI 06/05	73.033±0.122	8.336±0.107	—
	SofI 06/06	73.120±0.102	8.327±0.094	—

2.36 mas/yr) are fully consistent with our conclusion that this object and the planet host star HD 101930 A form a common proper motion pair. In addition, Kharchenko (2001) also lists the optical magnitude of HD 101930 B ($V = 10.605 \pm 0.063$ mag).

The detection limit of our SofI H-band images of both planet host stars is illustrated in Fig. 3. We obtain similar limits for both planet host stars. In the background limited region beyond ~ 15 arcsec (~ 530 AU of projected separation in case of HD 65216 and ~ 460 AU in case of HD 101930, respectively), a limiting magnitude of $H \sim 17$ mag is achieved. This allows the detection of substellar companions with masses down to $\sim 65 M_{Jup}$, if we assume a system age of 5 Gyr for both planet host star. This limit has been derived using the Baraffe et al. (2003) evolutionary models. All stellar companions of the planet host stars are detectable at angular separations larger than ~ 5 arcsec (~ 180 AU of projected separation in case of HD 65216 A and ~ 150 AU in case of HD 101930 A, respectively) up to the edge of the SofI field of view imaged twice in both observing epochs, which is ~ 67 arcsec (2400 AU of projected separation) around HD 65216 A and ~ 59 arcsec (1800 AU of projected separation) around HD 101930 A. Beside HD 65216 B and HD 101930 B no further co-moving companions could be found within the SofI field of view around both planet host stars.

In the case that both detected co-moving companions are low-mass stars located at the respective distance of their primaries, we can approximate their masses from evolutionary stellar models.

In the case of HD 65216 B, only its apparent H-band magnitude is known, which is on average $H = 12.680 \pm 0.045$ mag. The distance modulus $E = 2.757 \pm 0.053$ mag of the planet host star was derived from the Hipparcos parallax. With the distance modulus and the apparent magnitude of HD 65216 B we derive its absolute magnitude to be $M_H = 9.923 \pm 0.069$ mag. For an assumed age of 5 Gyr for the HD 65216 AB system, we can derive the mass of HD 65216 B from evolutionary models of low-mass stars and substellar objects. According to the Baraffe et al. (1998) models, the

absolute magnitude of HD 65216 B is consistent with a low-mass star of $0.094 \pm 0.002 M_\odot$.

In the case of HD 101930 B, optical as well as infrared photometry is available. The Hipparcos parallax of the planet host star HD 101930 A yields a distance modulus $E = 2.421 \pm 0.064$ mag. With the given apparent H-band photometry of the companion we obtain its absolute magnitude $M_H = 4.870 \pm 0.080$ mag. If we assume again 5 Gyr as the age of the HD 101930 AB system we obtain $0.666 \pm 0.013 M_\odot$ as the mass of HD 101930 B using the Baraffe et al. (1998) evolutionary models as well as the derived absolute H-band photometry of the companion.

The mass approximations described above have to be confirmed with spectroscopy, i.e. it has to be shown that the detected companions are indeed low-mass stellar objects. In particular companions as faint as HD 65216 B in the near infrared could also be white dwarfs. However, the spectra of these degenerated objects are clearly different to those of low-mass stars. Spectroscopy finally determines the true nature of the companions, which will also confirm their companionship to the planet host stars.

3 INFRARED SPECTROSCOPY

3.1 HD 65216 B and HD 101930 B

We obtained infrared H- and K-band spectroscopy of HD 65216 B in December 2006 with VLT-ISAAC, the infrared imager and spectrograph on UT1 (Antu) at Paranal observatory. We used ISAAC's low-resolution spectroscopy mode SWS1-LR with the 1 arcsec slit, providing a resolving power of 500 in H-band, and 450 in K-band, with a dispersion of 4.8 \AA per pixel in H-band, and 7.2 \AA per pixel in K-band.

In the H-band we took 12 frames each the average of two 30 s integrations, i.e. 12 min of total integration time. In order to remove the high infrared background, the telescope was always nodded 50 arcsec between two positions along the slit. In addition we applied a 5 arcsec dither to the nodding positions in order to avoid that the spectrum always falls on the same pixels on the ISAAC detector. We took 14 frames in

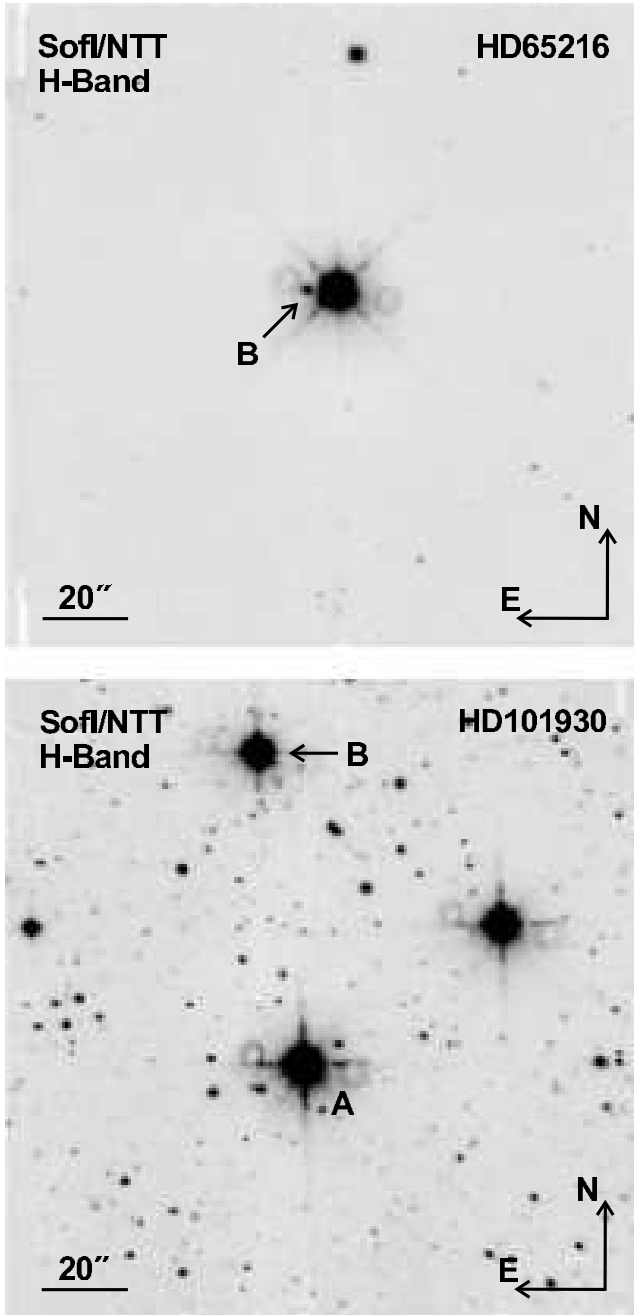


Figure 1. The SofI small field images of the planet host stars HD 65216 (top) and HD 101930 (bottom), taken in June 2006 in the H-band. The planet host stars are the bright stars in the center of the images and the newly found co-moving companions are marked with a black arrow. Both images show additional companion-candidates around the planet host stars down to a limiting magnitude ($S/N = 10$) of $H \sim 17$ mag, none of which are co-moving.

K-band, each the average of two 30 s integrations, i.e. 14 min of total integration time. For wavelength calibration we took spectra of a Xenon lamp. All frames were flat-fielded and the spectra are extracted from the individual frames, wavelength calibrated and finally averaged using standard IRAF data reduction routines. Telluric features were removed, dividing by a spectrum of the telluric standard star HIP 52670 (B3V)

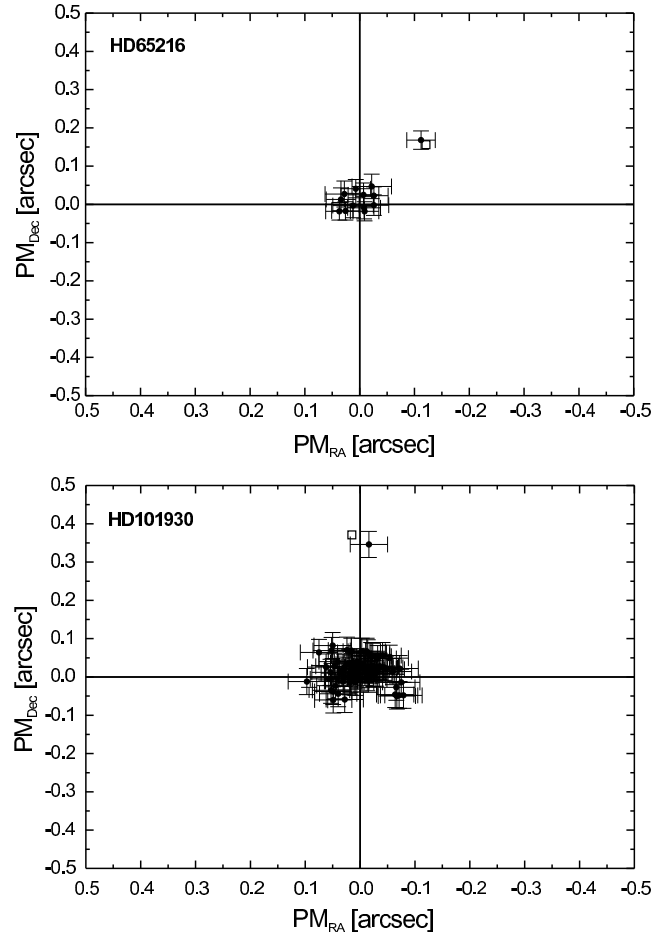


Figure 2. The measured proper motions of all detected ($S/N > 10$) companion-candidates around the planet host stars HD 65216 (top) and HD 101930 (bottom) between the SofI observing runs in June 2005 and June 2006. Most of the detected candidates exhibit only small or even negligible proper motions, i.e. these sources are not companions of the fast moving planet host stars. In contrast, two sources clearly share the proper motions of the planet host stars, which are indicated as boxes. The position of these two co-moving companions HD 65216 B and HD 101930 B are indicated in Fig. 1 and the SofI astrometry and photometry is summarized in Tab. 2.

which was taken between the H- and K-band spectroscopy of HD 65216 B. Thus, the airmass difference between science and calibration spectra was minimized to less than 0.1. The spectral response function of ISAAC was determined, using the spectra of the telluric standard and flux-calibrated B3V spectra from the spectral library of Pickles et al. (1998).

The spectra of the wide companion HD 101930 B were taken at the beginning of February 2007 with SofI in its low-resolution spectroscopy mode. We used the grism RED in combination with a 1 arcsec slit, providing a resolving power of 588 in H- and K-band with a dispersion of 10.22 \AA per pixel. Six frames, each the average of 20 times 3 s integrations, yield a total integration time of 6 min. The NTT was nodded along the direction of the slit between two positions, separated from each other by 37 arcsec. In addition a random dither of 2 arcsec was applied around both nodding positions. A spectrum of a Xenon lamp was taken for wavelength calibration. All frames were flat-fielded and the indi-

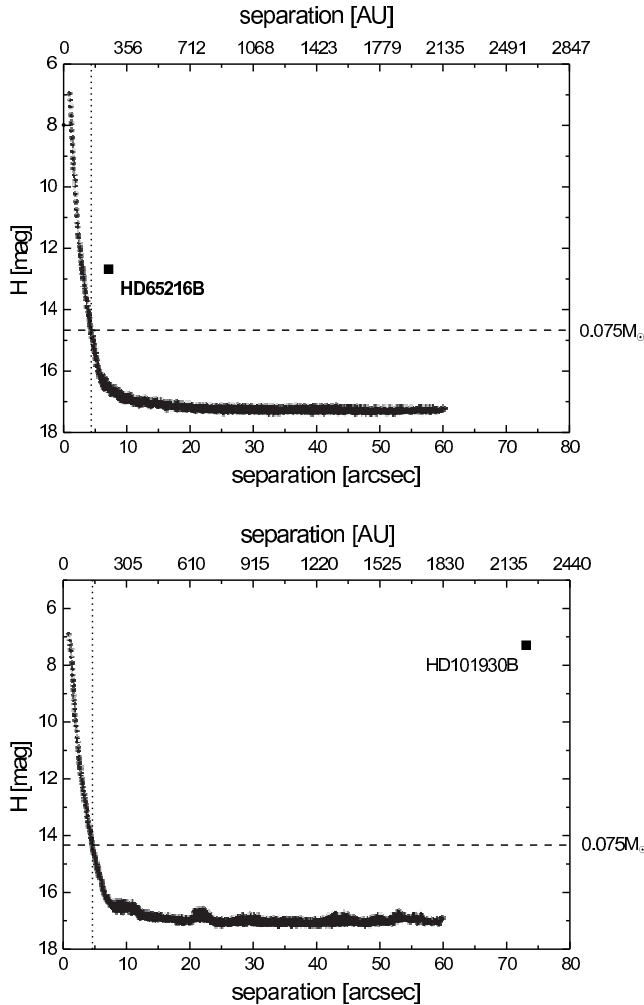


Figure 3. The detection limit ($S/N = 10$) of our SofI H-band imaging of the exoplanet host stars HD 65216 (top) and HD 101930 (bottom) plotted for a range of angular separations and projected separations. The detected co-moving companions HD 65216 B and HD 101930 B are indicated as black squares. The expected H-band magnitude of objects at the stellar-substellar border ($0.075 M_{\odot}$), is illustrated with a horizontal dashed line. All stellar companions can be detected at angular separations larger than ~ 5 arcsec (see dotted vertical line) up to the edge of the SofI field of view imaged twice in both observing epochs.

vidual spectra were extracted, wavelength calibrated and finally averaged using again standard IRAF routines. We took a spectrum of the telluric standard HIP 54930 (B1V) immediately after HD 101930 B to minimize airmass difference between the science and calibration observations to less than 0.1. Telluric features in the spectra of HD 101930 B were removed with the spectra of the telluric standard, which was again used together with the flux-calibrated spectra from the spectral library of Pickles et al. (1998) to determine the spectral response function of SofI.

The reduced and flux-calibrated H- and K-band spectra of HD 65216 B and HD 101930 B are shown in Fig. 4 and Fig. 5. We compare the H- and K-band spectra of both companions with template spectra from the IRTF spectral library (Cushing et al. 2005). To compare our SofI and ISAAC spectra with these templates, the template spectra were

smoothed to the same resolution ($\Delta\lambda/\lambda = 1/500$) in the H- and K-band.

The continua of the H- and K-band spectra of HD 65216 B as well as all detected atomic and molecular features are mostly consistent with comparison spectra of spectral type M7V and M8V. In the H-band the most prominent features in the spectrum of HD 65216 B are those of Potassium at $1.517 \mu\text{m}$, the line series of FeH (strongest feature at $1.625 \mu\text{m}$) as well as the flux depression induced by H_2O at wavelength longer than $1.75 \mu\text{m}$. The overall shape of the continuum in the H-band is due to collision induced absorption (CIA) by H_2 . In the K-band atomic features of Sodium (Na doublet at $2.208 \mu\text{m}$) and Calcium (doublet at $2.265 \mu\text{m}$) are detected. However, the strongest features in the K-band spectrum are those of the CO series extending from the band head at $2.294 \mu\text{m}$ to longer wavelength. At wavelength longer than $2.3 \mu\text{m}$ we see again a flux depression induced by H_2O , typical for a dwarf of spectral type M7 to M8.

In the H-band spectrum of HD 101930 B the most prominent spectral features are the atomic absorption lines of Magnesium at $1.504 \mu\text{m}$, $1.576 \mu\text{m}$, $1.711 \mu\text{m}$, Silicon at $1.589 \mu\text{m}$ and Aluminium at $1.674 \mu\text{m}$. The detected absorption features as well as the continuum of the H-Band spectrum of the companion are consistent with those of comparison spectra of M0 to M1 dwarfs.

The same holds for the K-band spectrum of HD 101930 B where we find the strong absorption line doublets of Sodium at $2.208 \mu\text{m}$ and Calcium $2.265 \mu\text{m}$ as well as the CO absorption band at wavelength longer than $2.294 \mu\text{m}$. In addition the weaker absorption lines of the Sodium doublet at $2.337 \mu\text{m}$, the absorption lines of Magnesium at $2.107 \mu\text{m}$ and $2.282 \mu\text{m}$, as well as Aluminium at $2.117 \mu\text{m}$ are detected.

The determined spectral types of HD 65216 B and HD 101930 B are fully consistent with the apparent magnitudes of both co-moving companions if one assumes that both objects are located at the distances of the planet host stars, as it is expected for real companions. Hence, the companionship of HD 65216 B and HD 101930 B revealed first by astrometry is finally confirmed by photometry and spectroscopy.

3.2 HD 16141 B

We reported a co-moving companion located ~ 6 arcsec (~ 220 AU of projected separation) south of the planet host star HD 16141 in Mugrauer et al. (2005). We determined the H-band photometry of the companion to be $H = 10.062 \pm 0.049$ mag. With the known distance of the planet host star (Hipparcos parallax $\pi = 27.85 \pm 1.39$ mas) this yields $M_H = 7.286 \pm 0.119$ mag as absolute magnitude of the companion. By assuming that the companion is a low-mass stellar object the mass of the companion was determined using again the stellar evolutionary models from Baraffe et al. (1998). For an assumed age of the companion of 5 Gyr we obtain $0.286 \pm 0.017 M_{\odot}$. The expected color of such an object is also given by the models to $V - K = 4.52 \pm 0.06$ mag. According to the spectral type – color relation from Kenyon & Hartmann (1995) the derived color is consistent with a M3 dwarf.

In order to confirm this result and to finally to deter-

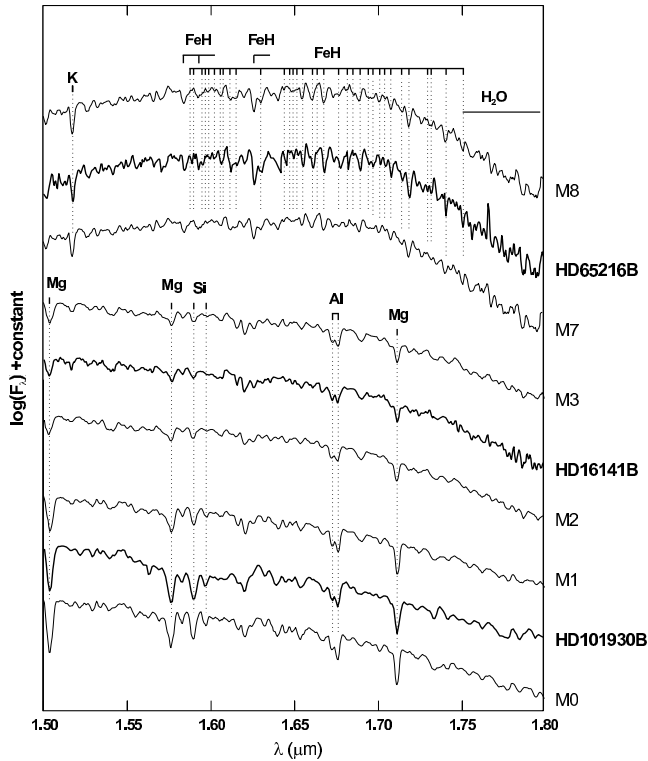


Figure 4. The ISAAC H-band spectra of HD 65216 B and HD 16141 B and the SofI H-band spectrum of HD 101930 B together with comparison spectra of dwarfs from the IRTF Spectral Library (Cushing et al. 2005). The most prominent spectral atomic and molecular features are indicated. The shape of the continuum as well as all detected spectral features of the spectrum of HD 101930 B are consistent with the comparison H-band spectra of M0 and M1 dwarfs. The H-band spectrum of HD 16141 B is most comparable with those of M2 to M3 dwarfs and the spectrum of HD 65216 B with those of M7 to M8 dwarfs.

mine the true nature of HD 16141 B we obtained follow-up spectra in October 2006 with ISAAC, using the same setup as for HD 65216 B. For correction of telluric features and for the flux-calibration we observed the telluric standard Hip 15188 (B3V). The reduced H- and K-band spectra of HD 16141 B are shown in Fig. 4 and Fig. 5.

The continua of the H- and K-band spectra as well as all detected atomic and molecular absorption features are consistent with a spectral type in the range M2V to M3V, i.e. HD 16141 B is a low mass stellar object as it was already expected from its photometry, adopting the distance of the planet host star for its companion.

4 DISCUSSION

As described in the last two sections we can confirm the companionship of HD 65216 B and HD 101930 B detected first by astrometry as co-moving objects to the planet host stars HD 65216 A and HD 101930 A, with photometry and spectroscopy. The photometry of both companions is consistent with low-mass stellar objects located at the distances of the planet host stars, which is finally confirmed with ISAAC and SofI spectroscopy.

HD 101930 B is separated from its primary by ~ 73 arcsec which corresponds to a projected separation of

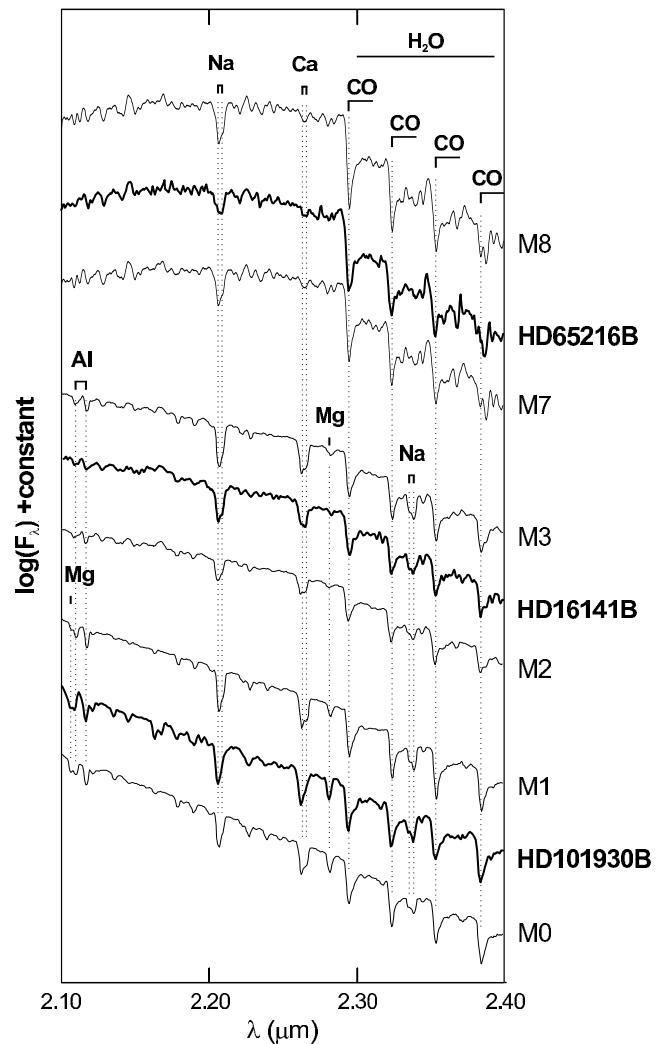


Figure 5. The ISAAC K-band spectra of HD 65216 B and HD 16141 B and the SofI K-band spectrum of HD 101930 B together with comparison spectra of dwarfs from the IRTF spectral library (Cushing et al. 2005). The most prominent spectral atomic and molecular features are indicated. The shape of the continuum as well as all detected spectral features of the spectrum of HD 101930 B are consistent with the comparison K-band spectra of M0 and M1 dwarfs. The K-band spectrum of HD 16141 B is most comparable with those of M2 to M3 dwarfs and the spectrum of HD 65216 B with those of M7 to M8 dwarfs.

2229 AU at the distance of the planet host star HD 101930 A. With the mass of the planet host star ($0.74 M_\odot$) and its stellar companion ($0.666 M_\odot$) as well as with the separation of the system we can approximate the longtime stable region for additional companions as derived by Holman & Wiegert (1999) for assumed circular companion orbits. By assuming an orbital eccentricity $e = 0.5$ for HD 101930 B we obtain $a_c = 270$ AU and $a_c = 633$ AU for a circular ($e = 0$) orbit, respectively. Thus, the planet of HD 101930 A clearly resides well within the longtime stable region of its host star.

4.1 Evidence for the binarity of HD 65216 B

HD 65216 B is separated from its primary by ~ 7 arcsec which corresponds to a projected separation of 253 AU at the distance of the planet host star HD 65216 A. Besides our SofI

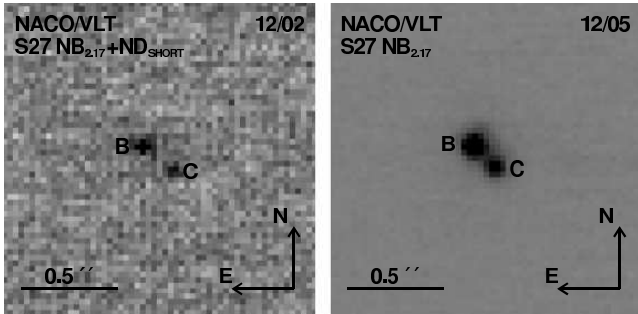


Figure 6. NACO images of HD 65216 B taken in the K-band through the narrow band filter NB_{2.17}. The co-moving companion is resolved in two objects B and C, separated by less than 0.2 arcsec.

H-band observations the HD 65216 system was also observed with the adaptive optics system NACO at UT4 (Yepun) at Paranal observatory. We retrieved public data from the ESO archive obtained with the S27 camera (pixel scale: 27.15 mas per pixel and 28 arcsec×28 arcsec field of view) of NACO in December 2002 and December 2005. In the first observing run 28 frames, each the average of two 15 s integrations, were taken in dither mode through the narrow band filter NB_{2.17} and the neutral density filter ND_{SHORT}, i.e. 14 min of total integration time. In the second run again 28 frames were taken in dither mode, each the average of 60 integrations of 0.5 s through the narrow band filter NB_{2.17}, i.e. again 14 min of total integration time. The images were flat-fielded and combined using the data reduction package *ECLIPSE* (Devillard 2001). At the position of HD 65216 B two objects are detected which are shown in Fig. 6 for both NACO observing epochs.

The brighter source B is separated by only 189 ± 11 mas from the fainter object C in the first epoch NACO image from December 2002 (they could also be called Ba and Bb, but we prefer B and C). In the second epoch NACO image both sources are separated by only 146 ± 3 mas, i.e. the separation significantly decreased by $\Delta sep = -43 \pm 12$ mas. If we assume that the brighter component B follows the proper motion of the planet host star but the faint source C is just a non-moving background source, the expected change of separation should be much larger, namely $\Delta sep = -423$ mas (15.6 NACO S27-pixels) for the given epoch difference between both NACO observation runs. This expected change of separation is about ten times larger than the one we measured. Hence, we conclude that B and C are co-moving objects, i.e. the HD 65216 system is a hierarchical triple system composed of the planet host star HD 65216 A which is orbited by the close binary system HD 65216 BC at a wide separation (253 AU) and by a planet candidate at close separation (1.37 AU).

The measured change of the separation between the B and C components can be explained by orbital motion of the B and C components around their common center of mass. In order to estimate this orbital motion we have to determine first the masses of both components.

In the second epoch narrow band NACO images all three components of the HD 65216 system are detected within the linearity limit of the NACO detector. We determine a magnitude difference of $\Delta NB_{2.17}(AB) = 6.31 \pm$

0.02 mag and $\Delta NB_{2.17}(AC) = 7.32 \pm 0.05$ mag. With the given 2MASS K_S -band magnitude of HD 65216 A we can approximate the K_S -band magnitudes of HD 65216 B and C and obtain $K_S(B) = 12.64 \pm 0.03$ mag and $K_S(C) = 13.65 \pm 0.06$ mag. With the known distance of the planet host star this finally yields the absolute K_S -band magnitudes of the two components $M_{K_S}(B) = 9.88 \pm 0.06$ mag and $M_{K_S}(C) = 10.89 \pm 0.08$ mag.

According to the spectral type – magnitude relation from Cruz et al. (2003) these values are consistent with low-mass objects of spectral type M7 to M8 for HD 65216 B and L2 to L3 for HD 65216 C. The absolute H-band magnitude of a M7 to M8 dwarf is $M_H = 10.3 \pm 0.3$ mag and $M_H = 11.5 \pm 0.2$ mag for objects of spectral types between L2 to L3. The same result is obtained by an independent analysis of the same public NACO datasets done by A. Eggenberger (private communication), see Eggenberger et al. (2007, in preparation). Hence, the total magnitude of the unresolved HD 65216 BC system should be $M_H = 9.99 \pm 0.24$ mag, which corresponds to an apparent magnitude of $H = 12.75 \pm 0.25$ mag at the distance of the planet host star. It is worth to mention that the SofI H-band photometry of the unresolved pair HD 65216 BC $H = 12.680 \pm 0.045$ mag is fully consistent with the derived magnitude estimate.

If we assume a system age of 5 Gyr we can use again the Baraffe et al. (1998) models to derive the masses of both components. We obtain $0.089 \pm 0.001 M_\odot$ for HD 65216 B and $0.078 \pm 0.001 M_\odot$ for HD 65216 C, respectively (since the system is older according to its metallicity, the true masses may be slightly larger). Hence the total mass of HD 65216 BC is $0.167 M_\odot$. The average separation of both components is 167 mas, which corresponds to a projected separation of 6 AU at the distance of the planet host star. We can use this separation as estimate for the semi-major axis of the system and finally derive its orbital period using Kepler’s third law, which yields 36 years. The maximal expected change of separation between both components is 19 mas/yr. Thus, for an epoch difference of three years the expected maximal change of separation due to orbital motion should be smaller than 57 mas. Indeed, the measured change of separation between HD 65216 B and C ($\Delta sep = -43 \pm 12$ mas) can be explained with orbital motion of both objects around their barycenter. This relatively short orbital motion is important, because it will yield directly determined masses from astrometry and Kepler’s third law within a few decades, which are very rare at such late spectral types and low masses, hence will be very useful for calibrating models and to constrain the mass-luminosity relation at the low-mass end.

Finally, we can determine the radius of the longterm stable region around the planet host star, using again the approximation of Holman & Wiegert (1999) and the derived masses of HD 65216 B and C (total mass $0.167 M_\odot$), the mass of the planet host star ($0.94 M_\odot$) as well as the projected separation between the star and its binary companion (253 AU). We obtain $a_c = 42$ AU for an assumed eccentric orbit of HD 65216 BC with $e = 0.5$ and $a_c = 103$ AU for a circular orbit, respectively.

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